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TITLE: Vehicle wireless sensing and communication system

Abstract Text (1):
Wireless sensing and communication system including sensors located on the vehicle or in the vicinity of the vehicle and which provide information which is transmitted to one or more interrogators in the vehicle using wireless radio frequency transmission technology. Power to operate the sensor may be supplied by the interrogator. The sensors include tire pressure, temperature and acceleration monitoring sensors, weight or load measuring sensors, switches, temperature, acceleration, angular position, angular rate, angular acceleration, proximity, rollover, occupant presence, humidity, presence of fluids or gases, strain, road condition and friction, chemical sensors and other similar sensors providing information to a vehicle system, vehicle operator or external site. The sensors provide information about the vehicle and its interior or exterior environment, about individual components, systems, vehicle occupants, subsystems, or about the roadway, ambient atmosphere, travel conditions and external objects.

Brief Summary Text (2):
The invention relates to the field of vehicular sensor systems and more particularly, to the field of wireless sensing and communications for a vehicle.

Brief Summary Text (16):
One solution to this problem is to continuously monitor the pressure and perhaps the temperature in the tire. Pressure loss can be automatically detected in two ways: by directly measuring air pressure within the tire or by indirect tire rotation methods. Various indirect methods are based on the number of revolutions each tire makes over an extended period of time through the ABS system and others are based on monitoring the frequency changes in the sound emitted by the tire. In the direct detection case, a sensor is mounted into each wheel or tire assembly, each with its own identity. An on-board computer collects the signals, processes and displays the data and triggers a warning signal in the case of pressure loss.

Brief Summary Text (23):
The advent of microelectromechanical (MEMS) pressure sensors, especially those based on surface acoustical wave (SAW) technology, has now made the wireless and powerless monitoring of tire pressure feasible. This is the basis of the tire pressure monitors described below. According to a Frost and Sullivan report on the U.S. Micromechanical Systems (MEMS) market (June 1997): "A MEMS tire pressure sensor represents one of the most profound opportunities for MEMS in the automotive sector."

Brief Summary Text (26):
International Publication No. WO 01/07271 describes a tire pressure sensor that replaces the valve and valve stem in a tire.

Brief Summary Text (27):
U.S. Pat. No. 5,231,827 contains a good description and background of the tire-monitoring problem. The device disclosed, however, contains a battery and electronics and is not a SAW device. Similarly, the device described in U.S. Pat.

No. 5,285,189 contains a battery as do the devices described in U.S. Pat. Nos. 5,335,540 and 5,559,484. U.S. Pat. No. 5,945,908 applies to a stationary tire monitoring system and does not use SAW devices.

Brief Summary Text (28):
One of the first significant SAW sensor patents is U.S. Pat. No. 4,534,223. This patent describes the use of SAW devices for measuring pressure and also a variety of methods for temperature compensation but does not mention wireless transmission.

Brief Summary Text (30):
U.S. Pat. No. 5,698,786 relates to the sensors and is primarily concerned with the design of electronic circuits in an interrogator. U.S. Pat. No. 5,700,952 also describes circuitry for use in the interrogator to be used with SAW devices. In neither of these patents is the concept of using a SAW device in a wireless tire pressure monitoring system described. These patents also do not describe including an identification code with the temperature and/or pressure measurements in the sensors and devices.

Brief Summary Text (37):
It is an object of the invention to provide new and improved sensors for a vehicle which wirelessly transmit information about a state measured or detected by the sensor.

Brief Summary Text (44):
It is another object of the invention to utilize any of the foregoing sensors for a vehicular component control system in which a component, system or subsystem in the vehicle is controlled based on the information provided by the sensor.

Brief Summary Text (46):
In order to achieve one or more of the objects mentioned above, the wireless sensing and communication system in accordance with the invention includes sensors that are located on the vehicle or in the vicinity of the vehicle and which provide information which is transmitted to one or more interrogators in the vehicle by wireless radio frequency means, using wireless radio frequency transmission technology. In some cases, the power to operate a particular sensor is supplied by the interrogator while in other cases, the sensor is independently connected to either a battery, generator, vehicle power source or some source of power external to the vehicle.

Brief Summary Text (48):
The system can use one or more interrogators each having one or more antennas that transmit radio frequency energy to the sensors and receive modulated radio frequency signals from the sensors containing sensor and/or identification information. One interrogator can be used for sensing multiple switches or other devices. For example, an interrogator may transmit a chirp form of energy at 905 MHz to 925 MHz to a variety of sensors located within or in the vicinity of the vehicle. These sensors may be of the RFID electronic type or of the surface acoustic wave (SAW) type. In the electronic type, information can be returned immediately to the interrogator in the form of a modulated RF signal. In the case of SAW devices, the information can be returned after a delay. Naturally, one sensor can respond in both the electronic and SAW delayed modes.

Brief Summary Text (49):
When multiple sensors are interrogated using the same technology, the returned signals from the various sensors can be time, code, space or frequency multiplexed. For example, for the case of the SAW technology, each sensor can be provided with a different delay. Alternately, each sensor can be designed to respond only to a single frequency or several frequencies. The radio frequency can be amplitude or frequency modulated. Space multiplexing can be achieved through the use of two or

more antennas and correlating the received signals to isolate signals based on direction.

Brief Summary Text (52):
More particularly, the tire monitoring system of this invention actually comprises three separate systems corresponding to three stages of product evolution. Generation 1 is a tire valve cap that provides information as to the pressure within the tire as described below. Generation 2 requires the replacement of the tire valve stem, or the addition of a new stem-like device, with a new valve stem that also measures temperature and pressure within the tire or it may be a device that attaches to the vehicle wheel rim. Generation 3 is a product that is attached to the inside of the tire adjacent the tread and provides a measure of the diameter of the footprint between the tire and the road, the tire pressure and temperature, indications of tire wear and, in some cases, the coefficient of friction between the tire and the road.

Brief Summary Text (54):
For the generation 1 system, a valve cap contains a SAW material at the end of the valve cap, which may be polymer covered. This device senses the absolute pressure in the valve cap. Upon attaching the valve cap to the valve stem, a depressing member gradually depresses the valve permitting the air pressure inside the tire to communicate with a small volume inside the valve cap. As the valve cap is screwed onto the valve stem, a seal prevents the escape of air to the atmosphere. The SAW device is electrically connected to the valve cap, which is also electrically connected to the valve stem that acts as an antenna for transmitting and receiving radio frequency waves. An interrogator located within 20 feet of the tire periodically transmits radio waves that power the SAW device. The SAW device measures the absolute pressure in the valve cap that is equal to the pressure in the tire. U.S. Pat. Nos. 5,641,902, 5,819,779 and 4,103,549 illustrate a valve cap pressure sensor where a visual output is provided. Other related prior art includes U.S. Pat. No. 4,545,246.

Brief Summary Text (55):
The generation 2 system permits the measurement of both the tire pressure and tire temperature. In this case, the tire valve stem is removed and replaced with a new tire valve stem that contains a SAW device attached at the bottom of the valve stem. This device actually contains two SAW devices, one for measuring temperature and the second for measuring pressure through a novel technology discussed below. This second generation device therefore permits the measurement of both the pressure and the temperature inside the tire. Alternately, this device can be mounted inside the tire, attached to the rim or attached to another suitable location. An external pressure sensor is mounted in the interrogator to measure the pressure of the atmosphere to compensate for altitude and/or barometric changes.

Brief Summary Text (56):
The generation 3 device contains a pressure and temperature sensor, as in the case of the generation 2 device, but additionally contains one or more accelerometers which measure at least one component of the acceleration of the vehicle tire tread adjacent the device. This acceleration varies in a known manner as the device travels in an approximate circle attached to the wheel. This device is capable of determining when the tread adjacent the device is in contact with road surface. It is also able to measure the coefficient of friction between the tire and the road surface. In this manner, it is capable of measuring the length of time that this tread portion is in contact with the road and thereby provides a measure of the diameter of the tire footprint on the road. A technical discussion of the operating principle of a tire inflation and load detector based on flat area detection follows:

Brief Summary Text (59):
From the above, one can conclude that monitoring the curvature of the tire as it

rotates can provide a good indication of its operational state. A sensor mounted inside the tire at its largest diameter can accomplish this measurement. Preferably, the sensor would measure mechanical strain. However, a sensor measuring acceleration in any one axis could also serve the purpose.

Brief Summary Text (60):
In the case of the strain measurement, the sensor would indicate a constant strain as it spans the arc over which the tire is not in contact with the ground, and a pattern of increased stretch during the arc of close proximity with the ground. A simple ratio of the times of duration of these two states would provide a good indication of inflation, but more complex algorithms could be employed, where the values and the shape of the period of increased strain are utilized.

Brief Summary Text (67):
Generation 1 devices monitor pressure only while generation 2 devices also monitor the temperature and therefore will provide a warning of imminent tire failure more often than through monitoring pressure alone. Generation 3 devices will give an indication that the vehicle is overloaded before either a pressure or temperature monitoring system can respond. The generation 3 system can also be augmented to measure the vibration signature of the tire and thereby detect when a tire has worn to the point that the steel belt is contacting the road. In this manner, the generation 3 system also provides an indication of a worn out tire and, as will be discussed below, an indication of the road coefficient of friction.

Brief Summary Text (69):
Key advantages of the tire monitoring system disclosed herein over most of the currently known prior art are: very small size and insignificant weight eliminating the need for wheel counterbalance, cost competitive for tire monitoring only, significant cost advantage when systems are combined, exceeds customers' price targets, high update rate, self-diagnostic, automatic wheel identification, no batteries required--powerless, no wires required--wireless.

Brief Summary Text (71):
The monitoring of temperature and or pressure of a tire can take place infrequently. It is adequate to check the pressure and temperature of vehicle tires once every ten seconds to once per minute. To utilize the centralized interrogator of this invention, the tire monitoring system would preferably use SAW technology and the device could be located in the valve stem, wheel, tire side wall, tire tread, or other appropriate location with access to the internal tire pressure of the tires. A preferred system is based on a SAW technology discussed above.

Brief Summary Text (73):
An identification number can accompany each transmission from each tire sensor and can also be used to validate that the transmitting sensor is in fact located on the subject vehicle. In traffic situations, it is possible to obtain a signal from the tire of an adjacent vehicle. This would immediately show up as a return from more than five vehicle tires and the system would recognize that a fault had occurred. The sixth return can be easily eliminated, however, since it could contain an identification number that is different from those that have heretofore been returned frequently to the vehicle system or based on a comparison of the signals sensed by the different antennas. Thus, when the vehicle tire is changed or tires are rotated, the system will validate a particular return signal as originating from the tire-monitoring sensor located on the subject vehicle.

Brief Summary Text (74):
This same concept is also applicable for other vehicle-mounted sensors. This permits a plug and play scenario whereby sensors can be added to, changed, or removed from a vehicle and the interrogation system will automatically adjust. The system will know the type of sensor based on the identification number, frequency, delay and/or its location on the vehicle. For example, a tire monitor could have a

different code in the identification number from a switch or weight-monitoring device. This also permits new kinds of sensors to be retroactively installed on a vehicle. If a totally new type of the sensor is mounted to the vehicle, the system software would have to be updated to recognize and know what to do with the information from the new sensor type. By this method, the configuration and quantity of sensing systems on a vehicle can be easily changed and the system interrogating these sensors need only be updated with software upgrades which could occur automatically over the Internet.

Brief Summary Text (76):
With an accelerometer mounted in the tire, as is the case for the generation 3 system, information is present to diagnose other tire problems. For example, when the steel belt wears through the rubber tread, it will make a distinctive noise and create a distinctive vibration when it contacts the pavement. This can be sensed by the SAW accelerometer. The interpretation of various such signals can be done using neural network technology. Similar systems are described more detail in U.S. Pat. No. 5,829,782, incorporated by reference herein. As the tread begins to separate from the tire as in the Bridgestone cases, a distinctive vibration is created which can also be sensed by a tire-mounted accelerometer.

Brief Summary Text (83):
For strain gage weight sensing, the frequency of interrogation would be considerably higher than that of the tire monitor, for example. However, if the seat is unoccupied then the frequency of interrogation can be substantially reduced. For an occupied seat, information as to the identity and/or category and position of an occupying item of the seat can be obtained through the multiple weight sensors described. For this reason, and due to the fact that during the pre-crash event the position of an occupying item of the seat may be changing rapidly, interrogations as frequently as once every 10 milliseconds can be desirable. This would also enable a distribution of the weight being applied to the seat to be obtained which provides an estimation of the position of the object occupying the seat. Using pattern recognition technology, e.g., a trained neural network, sensor fusion, fuzzy logic, etc., the identification of the object can be ascertained based on the determined weight and/or determined weight distribution.

Brief Summary Text (97):
U.S. Pat. No. 4,249,418, incorporated by reference herein, is one of many examples of prior art SAW temperature sensors. Temperature sensors are commonly used within vehicles and many more applications might exist if a low cost wireless temperature sensor is available, i.e., the invention. The SAW technology can be used for such temperature sensing tasks. These tasks include measuring the vehicle coolant temperature, air temperature within passenger compartment at multiple locations, seat temperature for use in conjunction with seat warming and cooling systems, outside temperatures and perhaps tire surface temperatures to provide early warning to operators of road freezing conditions. One example, is to provide air temperature sensors in the passenger compartment in the vicinity of ultrasonic transducers used in occupant sensing systems as described in the current assignee's U.S. Pat No. 5,943,295 (Varga et al.), incorporated by reference herein, since the speed of sound in the air varies by approximately 20% from -40.degree. C. to 85.degree. C. The subject matter of this patent is included in the invention to form a part thereof. Current ultrasonic occupant sensor systems do not measure or compensate for this change in the speed of sound with the effect of significantly reducing the accuracy of the systems at the temperature extremes. Through the judicious placement of SAW temperature sensors in the vehicle, the passenger compartment air temperature can be accurately estimated and the information provided wirelessly to the ultrasonic occupant sensor system thereby permitting corrections to be made for the change in speed of sound.

Brief Summary Text (99):
U.S. Pat. Nos. 4,199,990, 4,306,456 and 4,549,436, all of which are incorporated by

reference herein, are examples of prior art SAW accelerometers. Most airbag crash sensors for determining whether the vehicle is experiencing a frontal or side impact currently use micromachined accelerometers. These accelerometers are usually based on the deflection of a mass which is sensed using either capacitive or piezoresistive technologies. SAW technology has heretofore not been used as a vehicle accelerometer or for vehicle crash sensing. Due to the importance of this function, at least one interrogator could be dedicated to this critical function. Acceleration signals from the crash sensors should be reported at least preferably every 100 microseconds. In this case, the dedicated interrogator would send an interrogation pulse to all crash sensor accelerometers every 100 microseconds and receive staggered acceleration responses from each of the SAW accelerometers wirelessly. This technology permits the placement of multiple low-cost accelerometers at ideal locations for crash sensing including inside the vehicle side doors, in the passenger compartment and in the frontal crush zone. Additionally crash sensors can now be located in the rear of the vehicle in the crush zone to sense rear impacts. Since the acceleration data is transmitted wirelessly, concern about the detachment or cutting of wires from the sensors disappears. One of the main concerns, for example, of placing crash sensors in the vehicle doors where they most appropriately can sense vehicle side impacts, is the fear that an impact into the A-pillar of the automobile would sever the wires from the door-mounted crash sensor before the crash was sensed. This problem disappears with the current wireless technology of this invention. If two accelerometers are placed at some distance from each other, the roll rate of the vehicle can be determined and thus the tendency of the vehicle to rollover can be predicted in time to automatically take corrective action and/or deploy a curtain airbag or other airbag(s).

Brief Summary Text (103):
The SAW technology is particularly applicable for gyroscopes as described in International Publication No. WO 00/79217A2 to Varadan et al. The output of such gyroscopes can be determined with an interrogator that is also used for the crash sensor accelerometers, or a dedicated interrogator can be used. Gyroscopes having an accuracy of approximately 1 degree per second have many applications in a vehicle including skid control and other dynamic stability functions. Additionally, gyroscopes of similar accuracy can be used to sense impending vehicle rollover situations in time to take corrective action.

Brief Summary Text (109):
Many sensing systems are available for the use to identify and locate occupants or other objects in a passenger compartment of the vehicle. Such sensors include ultrasonic sensors, chemical sensors (e.g. carbon dioxide), cameras, radar systems, heat sensors, capacitance, magnetic or other field change sensors, etc. Most of these sensors require power to operate and return information to a central processor for analysis. An ultrasonic sensor, for example, may be mounted in or near the headliner of the vehicle and periodically it transmits a few ultrasonic waves and receives reflections of these waves from occupying items of the passenger seat. Current systems on the market are controlled by electronics in a dedicated ECU.

Brief Summary Text (110):
An alternate method as taught in this invention is to use an interrogator to send a signal to the headliner-mounted ultrasonic sensor causing that sensor to transmit and receive ultrasonic waves. The sensor in this case would perform mathematical operations on the received waves and create a vector of data containing perhaps twenty to forty values and transmit that vector wirelessly to the interrogator. By means of this system, the ultrasonic sensor need only be connected to the vehicle power system and the information could be transferred to and from the sensor wirelessly. Such a system significantly reduces the wiring complexity especially when there may be multiple such sensors distributed in the passenger compartment. Now, only a power wire needs to be attached to the sensor and there does not need

to be any direct connection between the sensor and the control module. Naturally, the same philosophy would apply to radar-based sensors, electromagnetic sensors of all kinds including cameras, capacitive or other electromagnetic field change sensitive sensors etc. In some cases, the sensor itself can operate on power supplied by the interrogator through radio frequency transmission. In this case, even the connection to the power line can be omitted. This principle can be extended to the large number of sensors and actuators that are currently in the vehicle where the only wires that are needed are those to supply power to the sensors and actuators and the information is supplied wirelessly.

Brief Summary Text (112):
A significant number of people are suffocated each year in automobiles due to excessive heat, carbon dioxide, carbon monoxide, or other dangerous fumes. The SAW sensor technology is particularly applicable to solving these kinds of problems. The temperature measurement capabilities of SAW transducers have been discussed above. If the surface of a SAW device is covered with a material which captures carbon dioxide, for example, such that the mass, elastic constants or other property of surface coating changes, the characteristics of the surface acoustic waves can be modified as described in detail in U.S. Pat. No. 4,637,987 and elsewhere. Once again, an interrogator can sense the condition of these chemical-sensing sensors without the need to supply power and connect the sensors with either wireless communication or through the power wires. If a concentration of carbon monoxide is sensed, for example, an alarm can be sounded, the windows opened, and/or the engine extinguished. Similarly, if the temperature within the passenger compartment exceeds a certain level, the windows can be automatically opened a little to permit an exchange of air reducing the inside temperature and thereby perhaps saving the life of an infant or pet left in the vehicle unattended.

Brief Summary Text (114):
Each year a number of children and animals are killed when they are locked into a vehicle trunk. Since children and animals emit significant amounts of carbon dioxide, a carbon dioxide sensor connected to the vehicle system wirelessly and powerlessly provides an economic way of detecting the presence of a life form in the trunk. If a life form is detected, then a control system can release a trunk lock thereby opening the trunk. Alarms can also be sounded or activated when a life form is detected in the trunk.

Brief Summary Text (119):
An infrared sensor that looks down the highway in front of the vehicle can actually measure the road temperature prior to the vehicle traveling on that part of the roadway. This system also would not give sufficient warning if the operator waited for the occurrence of a frozen roadway. The probability of the roadway becoming frozen, on the other hand, can be predicted long before it occurs, in most cases, by watching the trend in the temperature.

Brief Summary Text (131):
An alternate approach for some applications, such as tire monitoring, where it is difficult to interrogate the SAW device as the wheel, and thus the antenna, is rotating, the transmitting power can be significantly increased if there is a source of energy inside the tire. Many systems now use a battery but this leads to problems related to having to periodically replace the battery and temperature effects. In some cases, the manufacturers recommend that the battery be replaced as often as every 6 to 12 months. Batteries also sometimes fail to function properly at cold temperatures and have their life reduced when operated at high temperatures. For these reasons, there is a strong belief that a tire monitoring system should obtain its power from some source external of the tire. Similar problems can be expected for other applications.

Brief Summary Text (135):

The term "gage" as used herein interchangeably with the terms "sensor" and "sensing device".

Drawing Description Text (10):
FIG. 4 is a detailed view of a polymer on SAW pressure sensor.

Drawing Description Text (13):
FIG. 5 is a perspective view of a SAW temperature sensor.

Drawing Description Text (18):
FIG. 8A is a view of a view of a SAW switch sensor for mounting on or within a surface such as a vehicle armrest.

Drawing Description Text (27):
FIG. 13 is a perspective view of a carbon dioxide SAW sensor for mounting in the trunk lid for monitoring the inside of the trunk for detecting trapped children or animals.

Drawing Description Text (28):
FIG. 13A is a detailed view of the SAW carbon dioxide sensor of FIG. 13.

Drawing Description Text (29):
FIG. 14 is an overhead view of a roadway with vehicles and a SAW road temperature and humidity monitoring sensor.

Drawing Description Text (30):
FIG. 14A is a detail drawing of the monitoring sensor of FIG. 14.

Drawing Description Text (32):
FIG. 16 is a partial cutaway view of a section of a fluid reservoir with a SAW fluid pressure and temperature sensor for monitoring oil, water, or other fluid pressure.

Drawing Description Text (34):
FIG. 17A is a cross section detail view of a vehicle spring and shock absorber system with a SAW torque sensor system mounted for measuring the stress in the vehicle spring of the suspension system of FIG. 17.

Drawing Description Text (35):
FIG. 17B is a detail view of a SAW torque sensor and shaft compression sensor arrangement for use with the arrangement of FIG. 17.

Drawing Description Text (37):
FIG. 19A is a perspective view of a SAW tilt sensor using four SAW assemblies for tilt measurement and one for temperature.

Drawing Description Text (38):
FIG. 19B is a top view of a SAW tilt sensor using three SAW assemblies for tilt measurement each one of which can also measure temperature.

Drawing Description Text (39):
FIG. 20 is a perspective exploded view of a SAW crash sensor for sensing frontal, side or rear crashes.

Drawing Description Text (41):
FIG. 21A is a cutaway view of the PVDF sensor of FIG. 21.

Drawing Description Text (43):
FIG. 22A is a top detailed view of a SAW pressure and temperature monitor for use in the system of FIG. 22.

Detailed Description Text (2):
Referring now to the drawings wherein the same reference numerals refer to the same or similar elements, a first embodiment of a valve cap 10 including a tire pressure monitoring system in accordance with the invention is shown generally at 10 in FIG. 1A. A tire 1 has a protruding, substantially cylindrical valve stem 2 which is shown in a partial cutaway view in FIG. 1A. The valve stem 2 comprises a sleeve 3 and a tire valve assembly 5. The sleeve 3 of the valve stem 2 is threaded on both its inner surface and its outer surface. The tire valve assembly 5 is arranged in the sleeve 3 and includes threads on an outer surface which are mated with the threads on the inner surface of the sleeve 3. The valve assembly 5 comprises a valve seat 4 and a valve pin 6 arranged in an aperture in the valve seat 4. The valve assembly 5 is shown in the open condition in FIG. 1A whereby air flows through a passage between the valve seat 4 and the valve pin 6.

Detailed Description Text (3):
The valve cap 10 includes a substantially cylindrical body 9 and is attached to the valve stem 2 by means of threads 8 arranged on an inner cylindrical surface of body 9 which are mated with the threads on the outer surface of the sleeve 3. The valve cap 10 comprises a valve pin depressor 14 arranged in connection with the body 9 and a SAW pressure sensor 11. The valve pin depressor 14 engages the valve pin 6 upon attachment of the valve cap 10 to the valve stem 2 and depresses it against its biasing spring, not shown, thereby opening the passage between the valve seat 4 and the valve pin 6 allowing air to pass from the interior of tire 1 into a reservoir or chamber 12 in the body 9. Chamber 12 contains the SAW pressure sensor 11 as described in more detail below.

Detailed Description Text (4):
Pressure sensor 11 is an absolute pressure-measuring device. It functions based on the principle that the increase in air pressure and thus air density in the chamber 12 increases the mass loading on a SAW device changing the velocity of surface acoustic wave on the piezoelectric material. The pressure sensor 11 is therefore positioned in an exposed position in the chamber 12.

Detailed Description Text (6):
Strain sensor 15 is thus a differential pressure-measuring device. It functions based on the principle that changes in the flexure of the membrane 13 can be correlated to changes in pressure in the chamber 12' and thus, if an initial pressure and flexure are known, the change in pressure can be determined from the change in flexure.

Detailed Description Text (7):
FIGS. 1A and 1B therefore illustrate two different methods of using a SAW sensor in a valve cap for monitoring the pressure inside a tire. The precise manner in which the SAW sensors 11,15 operate is discussed fully below but briefly, each sensor 11,15 includes an antenna and an interdigital transducer which receives a wave via the antenna from an interrogator which proceeds to travel along a substrate. The time in which the waves travel across the substrate and return to the interdigital transducer is dependent on the temperature, the mass loading on the substrate (in the embodiment of FIG. 1A) or the flexure of membrane 13 (in the embodiment of FIG. 1B). The antenna transmits a return wave which is receives and the time delay between the transmitted and returned wave is calculated and correlated to the pressure in the chamber 12 or 12'.

Detailed Description Text (9):
The speed of the surface acoustic wave on the piezoelectric substrate changes with temperature in a predictable manner as well as with pressure. For the valve cap implementations, a separate SAW device can be attached to the outside of the valve cap and protected with a cover where it is subjected to the same temperature as the SAW sensors 11 or 15 but is not subject to pressure or strain. This requires that

each valve cap comprise two SAW devices, one for pressure sensing and another for temperature sensing. Since the valve cap is exposed to ambient temperature, a preferred approach is to have a single device on the vehicle which measures ambient temperature outside of the vehicle passenger compartment. Many vehicles already have such a temperature sensor. For those installations where access to this temperature data is not convenient, a separate SAW temperature sensor can be mounted associated with the interrogator antenna, as illustrated below, or some other convenient place.

Detailed Description Text (11):
The valve stem assembly is shown generally at 20 and comprises a brass valve stem 7 which contains a tire valve assembly 5. The valve stem 7 is covered with a coating 21 of a resilient material such as rubber, which has been partially removed in the drawing. A metal conductive ring 22 is electrically attached to the valve stem 7. A rubber extension 23 is also attached to the lower end of the valve stem 7 and contains a SAW pressure and temperature sensor 24. The SAW pressure and temperature sensor 24 can be of at least two designs wherein the SAW sensor is used as an absolute pressure sensor as shown in FIG. 2A or an as a differential sensor based on membrane strain as shown in FIG. 2B.

Detailed Description Text (12):
In FIG. 2A, the SAW sensor 24 comprises a capsule 32 having an interior chamber in communication with the interior of the tire via a passageway 30. A SAW absolute pressure sensor 27 is mounted onto one side of a rigid membrane or separator 31 in the chamber in the capsule 32. Separator 31 divides the interior chamber of the capsule 32 into two compartments 25 and 26, with only compartment 25 being in flow communication with the interior of the tire. The SAW absolute pressure sensor 27 is mounted in compartment 25 which is exposed to the pressure in the tire through passageway 30. A SAW temperature sensor 28 is attached to the other side of the separator 31 and is exposed to the pressure in compartment 26. The pressure in compartment 26 is unaffected by the tire pressure and is determined by the atmospheric pressure when the device was manufactured and the effect of temperature on this pressure. The speed of sound on the SAW temperature sensor 28 is thus affected by temperature but not by pressure in the tire.

Detailed Description Text (13):
The operation of SAW sensors 27 and 28 is discussed elsewhere more fully but briefly, since SAW sensor 27 is affected by the pressure in the tire, the wave which travels along the substrate is affected by this pressure and the time delay between the transmission and reception of a wave can be correlated to the pressure. Similarly, since SAW sensor 28 is affected by the temperature in the tire, the wave which travels along the substrate is affected by this temperature and the time delay between the transmission and reception of a wave can be correlated to the temperature.

Detailed Description Text (14):
FIG. 2B illustrates an alternate configuration of sensor 24 where a flexible membrane 33 is used instead of the rigid separator 31 shown in the embodiment of FIG. 2A, and a SAW device is mounted on flexible member 33. In this embodiment, the SAW temperature sensor 28 is mounted to a different wall of the capsule 32. A SAW device 29 is thus affected both by the strain in membrane 33 and the absolute pressure in the tire. Normally, the strain effect will be much larger with a properly designed membrane 33.

Detailed Description Text (15):
The operation of SAW sensors 28 and 29 is discussed elsewhere more fully but briefly, since SAW sensor 28 is affected by the temperature in the tire, the wave which travels along the substrate is affected by this temperature and the time delay between the transmission and reception of a wave can be correlated to the temperature. Similarly, since SAW sensor 29 is affected by the pressure in the

tire, the wave which travels along the substrate is affected by this pressure and the time delay between the transmission and reception of a wave can be correlated to the pressure. In both of the embodiments shown in FIG. 2A and FIG. 2B, a separate temperature sensor is illustrated. This has two advantages. First, it permits the separation of the temperature effect from the pressure effect on the SAW device. Second, it permits a measurement of tire temperature to be recorded. Since a normally inflated tire can experience excessive temperature caused, for example, by an overload condition, it is desirable to have both temperature and pressure measurements of each vehicle tire

Detailed Description Text (25):
FIG. 4 illustrates an absolute pressure sensor based on surface acoustic wave (SAW) technology. A SAW absolute pressure sensor 50 has an interdigital transducer (IDT) 51 which is connected to antenna 52. Upon receiving an RF signal of the proper frequency, the antenna induces a surface acoustic wave in the material 53 which can be lithium niobate, quartz, zinc oxide, or other appropriate piezoelectric material. As the wave passes through a pressure sensing area 54 formed on the material 53, its velocity is changed depending on the air pressure exerted on the sensing area 54. The wave is then reflected by reflectors 55 where it returns to the IDT 51 and to the antenna 52 for retransmission back to the interrogator. The material in the pressure sensing area 54 can be a thin (such as one micron) coating of a polymer that absorbs or reversibly reacts with oxygen or nitrogen where the amount absorbed depends on the air density.

Detailed Description Text (26):
In FIG. 4A, two additional sections of the SAW device, designated 56 and 57, are provided such that the air pressure affects sections 56 and 57 differently than pressure sensing area 54. This is achieved by providing three reflectors. The three reflecting areas cause three reflected waves to appear, 59, 60 and 61 when input wave 62 is provided. The spacing between waves 59 and 60, and between waves 60 and 61 provides a measure of the pressure. This construction of a pressure sensor may be utilized in the embodiments of FIGS. 1A-3 or in any embodiment wherein a pressure measurement by a SAW device is obtained.

Detailed Description Text (27):
There are many other ways in which the pressure can be measured based on either the time between reflections or on the frequency or phase change of the SAW device as is well known to those skilled in the art. FIG. 4B, for example, illustrates an alternate SAW geometry where only two sections are required to measure both temperature and pressure. This construction of a temperature and pressure sensor may be utilized in the embodiments of FIGS. 1A-3 or in any embodiment wherein both a pressure measurement and a temperature measurement by a single SAW device is obtained.

Detailed Description Text (30):
A SAW temperature sensor 60 is illustrated in FIG. 5. Since the SAW material, such as lithium niobate, expands significantly with temperature, the natural frequency of the device also changes. Thus, for a SAW temperature sensor to operate, a material for the substrate is selected which changes its properties as a function of temperature, i.e., expands. Similarly, the time delay between the insertion and retransmission of the signal also varies measurably. Since speed of a surface wave is typically 100,000 times slower then the speed of light, usually the time for the electromagnetic wave to travel to the SAW device and back is small in comparison to the time delay of the SAW wave and therefore the temperature is approximately the time delay between transmitting electromagnetic wave and its reception.

Detailed Description Text (41):
Most SAW-based accelerometers work on the principle of straining the SAW surface and thereby changing either the time delay or natural frequency of the system. An alternate novel accelerometer is illustrated FIG. 9A wherein a mass 130 is attached

to a silicone rubber coating 131 which has been applied the SAW device. Acceleration of the mass in FIG. 9 in the direction of arrow X changes the amount of rubber in contact with the surface of the SAW device and thereby changes the damping, natural frequency or the time delay of the device. By this method, accurate measurements of acceleration, below 1 G are readily obtained. Furthermore, this device can withstand high deceleration shocks without damage. FIG. 9B illustrates a more conventional approach where the strain in a beam 137 caused by the acceleration acting on a mass 136 is measured with a SAW strain sensor 135.

Detailed Description Text (45):
FIG. 12 illustrates a central antenna mounting arrangement for permitting interrogation of the tire monitors for four tires and is similar to that described in U.S. Pat. No. 4,237,728, which is incorporated by reference herein. An antenna package 200 is mounted on the underside of the vehicle and communicates with devices 201 through their antennas as described above. In order to provide for antennas both inside (for example for weight sensor interrogation) and outside of the vehicle, another antenna assembly (not shown) can be mounted on the opposite side of the vehicle floor from the antenna assembly 200.

Detailed Description Text (47):
A chemical sensor 250 similar to the sensor of FIG. 5B is illustrated in FIG. 13A for mounting in a vehicle trunk as illustrated in FIG. 13. The chemical sensor 250 is designed to measure carbon dioxide concentration through the mass loading effects as described in U.S. Pat. No. 4,895,017, which is incorporated by reference herein, with a polymer coating selected that is sensitive to carbon dioxide. The speed of the surface acoustic wave is a function of the carbon dioxide level in the atmosphere. Section 252 of the SAW device contains a coating of such a polymer and the acoustic velocity in this section is a measure of the carbon dioxide concentration. Temperature effects are eliminated through a comparison of the sonic velocities in sections 251 and 252 as described above.

Detailed Description Text (48):
Thus, when trunk lid 260 is closed and a source of carbon dioxide such as a child or animal is trapped within the trunk, the chemical sensor 250 will provide information indicating the presence of the carbon dioxide producing object to the interrogator which can then release the trunk lock permitting trunk to automatically open. In this manner, the problem of children and animals suffocating in closed trunks is eliminated.

Detailed Description Text (49):
A similar device can be distributed at various locations within the passenger compartment of vehicle along with a combined temperature sensor. If the car has been left with a child or other animal while owner is shopping, for example, and if the temperature rises within the vehicle to an unsafe level or, alternately, if the temperature drops below an unsafe level, then the vehicle can be signaled to take appropriate action which may involve opening the windows or starting the vehicle with either air conditioning or heating as appropriate. Thus, through these simple wireless powerless sensors, the problem of suffocation either from lack of oxygen or death from excessive heat or cold can all be solved in a simple, low-cost manner through using the same interrogator as used for other devices such as tire monitoring.

Detailed Description Text (50):
Additionally, a sensitive layer on a SAW can be made to be sensitive to other chemicals such as water vapor for humidity control or alcohol for drunk driving control. Similarly, the sensitive layer can be designed to be sensitive to carbon monoxide thereby preventing carbon monoxide poisoning. Many other chemicals can be sensed for specific applications such as to check for chemical leaks in commercial vehicles, for example. Whenever such a sensor system determines that a dangerous situation is developing, an alarm can be sounded and/or the situation can be

automatically communicated to an off vehicle location through telematics, a cell phone such as a 911 call, the Internet or though a subscriber service such as OnStar.TM..

Detailed Description Text (54):
More particularly, geolocation technologies that rely exclusively on wireless networks such as time of arrival, time difference of arrival, angle of arrival, timing advance, and multipath fingerprinting offer a shorter time-to-first-fix (TTFF) than GPS. They also offer quick deployment and continuous tracking capability for navigation applications, without the added complexity and cost of upgrading or replacing any existing GPS receiver in vehicles. Compared to either mobile-station-based, stand-alone GPS or network-based geolocation, assisted-GPS (AGPS) technology offers superior accuracy, availability, and coverage at a reasonable cost. AGPS for use with vehicles would comprise a communications unit with a partial GPS receiver arranged in the vehicle, an AGPS server with a reference GPS receiver that can simultaneously "see" the same satellites as the communications unit, and a wireless network infrastructure consisting of base stations and a mobile switching center. The network can accurately predict the GPS signal the communication unit will receive and convey that information to the mobile, greatly reducing search space size and shortening the TTFF from minutes to a second or less. In addition, an AGPS receiver in the communication unit can detect and demodulate weaker signals than those that conventional GPS receivers require. Because the network performs the location calculations, the communication unit only needs to contain a scaled-down GPS receiver. It is accurate within about 15 meters when they are outdoors, an order of magnitude more sensitive than conventional GPS.

Detailed Description Text (57):
Achieving optimal performance of sensitivity assistance in TIA/EIA-95 CDMA systems is relatively straightforward because base stations and mobiles synchronize with GPS time. Given that global system for mobile communication (GSM), time division multiple access (TDMA), or advanced mobile phone service (AMPS) systems do not maintain such stringent synchronization, implementation of sensitivity assistance and AGPS technology in general will require novel approaches to satisfy the timing requirement. The standardized solution for GSM and TDMA adds time calibration receivers in the field--location measurement units--that can monitor both the wireless-system timing and GPS signals used as a timing reference.

Detailed Description Text (59):
AGPS provides a natural fit for hybrid solutions because it uses the wireless network to supply assistance data to GPS receivers in vehicles. This feature makes it easy to augment the assistance-data message with low-accuracy distances from receiver to base stations measured by the network equipment. Such hybrid solutions benefit from the high density of base stations in dense urban environments, which are hostile to GPS signals. Conversely, rural environments--where base stations are too scarce for network-based solutions to achieve high accuracy--provide ideal operating conditions for AGPS because GPS works well there.

Detailed Description Text (61):
A general SAW temperature and pressure gage which can be wireless and powerless is shown generally at 300 located in the sidewall 310 of a fluid container 320 in FIG. 16. A pressure sensor 301 is located on the inside of the container 320, where it measures deflection of the container wall, and the fluid temperature sensor 302 on the outside. The temperature measuring SAW 300 can be covered with an insulating material to avoid influence from the ambient temperature outside of the container 320.

Detailed Description Text (62):
A SAW load sensor can also be used to measure load in the vehicle suspension system powerless and wirelessly as shown in FIG. 17. FIG. 17A illustrates a strut 315 such

as either of the rear struts of the vehicle of FIG. 17. A coil spring 320 stresses in torsion as the vehicle encounters disturbances from the road and this torsion can be measured using SAW strain gages as described in U.S. Pat. No. 5,585,571 for measuring the torque in shafts. This concept is also disclosed in U.S. Pat. No. 5,714,695. The disclosures of both patents are incorporated herein by reference. The use of SAW strain gages to measure the torsional stresses in a spring, as shown in FIG. 17B, and in particular in an automobile suspension spring has, to the knowledge of the inventors, not been heretofore disclosed. In FIG. 17B, the strain measured by SAW strain gage 322 is subtracted from the strain measured by SAW strain gage 321 to get the temperature compensated strain in spring 320.

Detailed Description Text (64):
FIG. 18 illustrates a vehicle passenger compartment, and the engine compartment, with multiple SAW temperature sensors 330. SAW temperature sensors are distributed throughout the passenger compartment, such as on the A-pillar, on the B-pillar, on the steering wheel, on the seat, on the ceiling, on the headliner, and on the rear glass and generally in the engine compartment. These sensors, which can be independently coded with different IDs and different delays, can provide an accurate measurement of the temperature distribution within the vehicle interior. Such a system can be used to tailor the heating and air conditioning system based on the temperature at a particular location in the passenger compartment. If this system is augmented with occupant sensors, then the temperature can be controlled based on seat occupancy and the temperature at that location. If the occupant sensor system is based on ultrasonics than the temperature measurement system can be used to correct the ultrasonic occupant sensor system for the speed of sound within the passenger compartment. Without such a correction, the error in the sensing system can be as large as 20 percent.

Detailed Description Text (65):
In one case, the SAW temperature sensor can be made from PVDF film and incorporated within the ultrasonic transducer assembly. For the 40 kHz ultrasonic transducer case, for example, the SAW temperature sensor would return the several pulses sent to drive the ultrasonic transducer to the control circuitry using the same wires used to transmit the pulses to the transducer after a delay that is proportional to the temperature within the transducer housing. Thus a very economical device can add this temperature sensing function using much of the same hardware that is already present for the occupant sensing system. Since the frequency is low, PVDF could be fabricated into a very low cost temperature sensor for this purpose. Other piezoelectric materials could also be used.

Detailed Description Text (69):
There are many applications for which knowledge of the pitch and/or roll orientation of a vehicle or other object is desired. An accurate tilt sensor can be constructed using SAW devices. Such a sensor is illustrated in FIG. 19A and designated 350. This sensor 350 utilizes a substantially planar and rectangular mass 351 and four supporting SAW devices 352 which are sensitive to gravity. For example, the mass act to deflect a membrane on which the SAW device resides thereby straining the SAW device. Other properties can also be used for a tilt sensor such as the direction of the earth's magnetic field. SAW devices 352 are shown arranged at the comers of the planar mass 351, but it must be understood that this arrangement is a preferred embodiment only and not intended to limit the invention. A fifth SAW device 353 can be provided to measure temperature. By comparing the outputs of the four SAW devices 352, the pitch and roll of the automobile can be measured. This sensor 350 can be used to correct errors in the SAW rate gyros described above. If the vehicle has been stationary for a period of time, the yaw SAW rate gyro can initialized to 0 and the pitch and roll SAW gyros initialized to a value determined by the tilt sensor of FIG. 19A. Many other geometries of tilt sensors utilizing one or more SAW devices can now be envisioned for automotive and other applications. In particular, an alternate preferred configuration is illustrated in FIG. 19B where a triangular geometry is used. In this embodiment,

the planar mass is triangular and the SAW devices 352 are arranged at the comers, although as with FIG. 19A, this is a non-limiting, preferred embodiment.

Detailed Description Text (71):
The SAW accelerometer for this particular crash sensor design is housed in a container 361 which is assembled into a housing 362 and covered with a cover 363. This particular implementation shows a connector 364 indicating that this sensor would require power and the response would be provided through wires. Alternately, as discussed for other devices above, the connector 364 can be eliminated and the information and power to operate the device transmitted wirelessly. Such sensors can be used as frontal, side or rear impact sensors. They can be used in the crush zone, in the passenger compartment or any other appropriate vehicle location. If two such sensors are separated and have appropriate sensitive axes, then the angular acceleration of the vehicle can be also be determined. Thus, for example, forward-facing accelerometers mounted in the vehicle side doors can used to measure the yaw acceleration of the vehicle. Alternately two vertical sensitive axis accelerometers in the side doors can be used to measure the roll acceleration of vehicle, which would be useful for rollover sensing.

Detailed Description Text (72):
Although piezoelectric SAW devices normally use rigid material such as quartz or lithium niobate, it is also possible to utilize polyvinylidene fluoride (PVDF) providing the frequency is low. A piece of PVDF film can also be used as a sensor of tire flexure by itself. Such a sensor is illustrated in FIGS. 21 and 21A at 400. The output of flexure of the PVDF film can be used to supply power to a silicon microcircuit that contains pressure and temperature sensors. The waveform of the output from the PVDF film also provides information as to the flexure of an automobile tire and can be used to diagnose problems with the tire as well as the tire footprint in a manner similar to the device described in FIG. 3. In this case, however, the PVDF film supplies sufficient power to permit significantly more transmission energy to be provided. The frequency and informational content can be made compatible with the SAW interrogator described above such that the same interrogator can be used. The power available for the interrogator, however, can be significantly greater thus increasing the reliability and reading range of the system.

Detailed Description Text (86):
SAW sensors can facilitate compliance with U.S. regulations concerning evaporative system monitoring in vehicles, through a SAW fuel vapor pressure and temperature sensors that measure fuel vapor pressure within the fuel tank as well as temperature. If vapors leak into the atmosphere, the pressure within the tank drops. The sensor notifies the system of a fuel vapor leak, resulting in a warning signal to the driver and/or notification to a repair facility. This application is particularly important since the condition within the furl tank can be ascertained wirelessly reducing the chance of a fuel fire in an accident. The same interrogator that monitors the tire pressure SAW sensors can also monitor the fuel vapor pressure and temperature sensors resulting in significant economies.

Detailed Description Text (87):
A SAW humidity sensor can be used for measuring the relative humidity and the resulting information can be input to the engine management system or the heating, ventilation, and air conditioning (14VAC) system for more efficient operation. The relative humidity of the air entering an automotive engine impacts the engine's combustion efficiency; i.e., the ability of the spark plugs to ignite the fuel/air mixture in the combustion chamber at the proper time. A SAW humidity sensor in this case can measure the humidity level of the incoming engine air, helping to calculate a more precise fuel/air ratio for improved fuel economy and reduced emissions.

Detailed Description Text (88):

Dew point conditions are reached when the air is fully saturated with water. When the cabin dew point temperature matches the windshield glass temperature, water from the air condenses quickly, creating frost or fog. A SAW humidity sensor with a temperature-sensing element and a window glass-temperature-sensing element can prevent the formation of visible fog formation by automatically controlling the HVAC system.

Detailed Description Text (89):
Thus, disclosed above is a tire with an integral monitoring system, two spaced beads comprising steel wire, a tread, sidewalls, an innerliner and plies. The monitoring system comprises a tire monitor fixed opposite the tread and including a plurality of SAW sensors, a first SAW sensor measuring tangential and/or radial acceleration. Another SAW sensor is arranged to measure pressure of the tire while another can be arranged to measure temperature of the tire.

Detailed Description Text (90):
Another integral monitoring system comprises an elongate body extending through the wheel rim from an inward side of the wheel rim to an outward side of the wheel rim, a transducer arranged on one end of the body and arranged to provide a measurement of at least one of the temperature and pressure in a tire when a tire is mounted on the wheel rim, an antenna arranged on another end of the body, and an inductive wire coupling the transducer to the antenna to enable transmission of a signal related to the measurement provided by the transducer. Insulating material is optionally arranged over the body to prevent contact between the body and the wheel rim.

Detailed Description Text (91):
One embodiment of a SAW sensor in accordance with the invention comprises a substrate made of a material on which a wave is capable of traveling, an interdigital transducer arranged in connection with the substrate, an antenna coupled to the interdigital transducer, at least one reflector spaced from the interdigital transducer, and at least one coating of a material sensitive to pressure arranged on the substrate between the interdigital transducer and the reflector such that the sensor provides a measurement of pressure. The coating may be an oxygen or nitrogen absorbent or reactive material, or made of at least one polymer.

Detailed Description Text (93):
When two reflectors are provided, the substrate can be made of a material which changes as a function of temperature. In this case, the interdigital transducer may be arranged between the reflectors such that the sensor provides a measurement of both pressure and temperature. A flexible membrane may be arranged over the sensor.

Detailed Description Text (94):
Another embodiment of a SAW sensor in accordance with the invention comprises a substrate made of a material on which a wave is capable of traveling and which changes as a function of temperature, a first interdigital transducer arranged on the substrate, an antenna coupled to the first interdigital transducer, and a thermister arranged on the substrate spaced from the first interdigital transducer such that the sensor provides a measurement of temperature.

Detailed Description Text (95):
Yet another embodiment of a SAW sensor in accordance with the invention comprises a substrate made of a material on which a wave is capable of traveling, first and second interdigital transducers arranged on the substrate, at least one antenna coupled to the first and second interdigital transducers, and first and second reflectors spaced from the at least one interdigital transducer such that two properties of the substrate are measured. A coating of a material sensitive to pressure is optionally arranged on the substrate between the first interdigital

transducer and the first reflector. The coating can comprise at least one oxygen or nitrogen sensing material. If two antennas are provided, each may be coupled to a respective one of the first and second interdigital transducers. Optionally, a material is arranged on the substrate which is sensitive to the presence or concentration of a gas, vapor, or liquid chemical. Also, a coating of a material sensitive to carbon dioxide may be arranged on the substrate between the first interdigital transducer and the first reflector.

Detailed Description Text (96):
Still another embodiment of a SAW sensor in accordance with the invention comprises a substrate made of a material on which a wave is capable of traveling, an interdigital transducer arranged in connection with the substrate, an antenna coupled to the interdigital transducer, at least one reflector spaced from the interdigital transducer, and at least one coating of a material sensitive to carbon dioxide arranged on the substrate between the interdigital transducer and the reflector such that the sensor provides a measurement of the presence of carbon dioxide. Such a SAW sensor is optimally arranged in an interior of a vehicle trunk. In this case, an automatic trunk opening device is coupled to the sensor such that upon the sensor detecting carbon dioxide in the interior of the trunk indicative of the presence of a life form, the automatic trunk opening device opens the trunk. An interrogator may be provided to interrogate the sensor and be coupled to the automatic trunk opening device.

Detailed Description Text (97):
One embodiment of a switch for a vehicle in accordance with the invention comprises a SAW sensor having a substrate, an interdigital transducer arranged on the substrate and a reflector arranged on the substrate spaced from the interdigital transducer; and a material sheet including a projection in engagement with the substrate in a space between the interdigital transducer and the reflector such that pressure on the substrate is transferred by the projection to the substrate.

Detailed Description Text (98):
Another embodiment of a switch comprises a SAW sensor having a substrate, an interdigital transducer arranged on the substrate, a reflector arranged on the substrate spaced from the interdigital transducer and a projection arranged on the substrate between the interdigital transducer and the reflector, and a material sheet arranged in engagement with the projection such that pressure on the substrate is transferred by the projection to the substrate.

Detailed Description Text (99):
An embodiment of an accelerometer in accordance with the invention comprises a SAW sensor having a substrate, an interdigital transducer arranged on the substrate, a reflector arranged on the substrate spaced from the interdigital transducer, an interface material adjacent to the substrate between the interdigital transducer and the reflector, and an acceleration-sensing mass arranged on the interface material whereby acceleration of the mass changes pressure on the substrate and thereby dampens or changes the speed on a surface wave on the substrate. The interface material may be a silicone rubber foam.

Detailed Description Text (100):
In one embodiment of a method for operating an interrogator for interrogating at least one SAW sensor, the following steps are performed: generating and transmitting two frequencies, F1 and F1+F2, from the interrogator during a burst time; continuing transmission of frequency F1 after the burst time until a frequency F2 is received from the at least one SAW sensor; receiving the two frequencies at the at least one SAW sensor; and mixing the two frequencies to yield a frequency F2 which is modulated by the at least one SAW sensor and contains the information about the measurement being performed by the at least one SAW sensor. The two frequencies may be generated using an oscillator and a mixer.

Detailed Description Text (101):
An embodiment of a tire monitoring system in accordance with the invention comprises an antenna package comprising a microstrip or stripline antenna array and a SAW sensor associated with each tire and including an antenna adapted to receive data from and transmit data to the antenna array. The antennas of the antenna array which face each tire may be in an X configuration such that the transmissions to and from the tires can be accomplished regardless of tire rotation angle.

Detailed Description Text (102):
In one embodiment of a method for monitoring tire temperature and pressure, the following steps are performed: mounting sensors in positions to obtain a reading of the temperature and/or pressure of tires, the sensors being sensitized to react to a transmission at a particular frequency, mounting an interrogator on the vehicle adapted to receive communications from the sensors, periodically sending a signal at the frequency to which the sensors are sensitized causing the sensors to respond and transmit a signal containing the temperature and/or pressure of the associated tire, and processing the signals from the sensors to obtain an indication of the temperature and/or pressure of the tires. Further, the temperature and/or pressure of the tires can be analyzed to determine if the tires are deflated, experiencing or about to experience tread separation or are overheating. The driver may be notified or indicia to the driver displayed, of the condition of the tires. At least one of the sensors may be mounted to a valve stem of a tire. The interrogator may be provided with several antennas spaced apart from one another such that a comparison of the signal from the sensors enables the location of each of the sensors to be approximately determined. The sensors can use surface acoustic wave technology wherein a radio frequency wave is converted into an acoustic wave which then travels on the surface of a material whereby the acoustic wave is modified based on a state being measured by the sensor and the modified wave is sensed by one or more interdigital transducers and converted back to a radio frequency wave which is used to excite an antenna for transmitting the wave to interrogator. The interrogator may be positioned relative to the sensors such that the distance between each of the sensors and the interrogator is different.

Detailed Description Text (103):
An embodiment of a system for controlling deployment of an occupant restraint device in accordance with the invention comprises acceleration sensors for measuring accelerations of the vehicle or a part thereof, each sensor including a receiving unit for receiving a radio frequency signal, first conversion means for converting the radio frequency signal into an acoustic wave, means for causing the acoustic wave to be modified based on the measured acceleration, second conversion means for converting the modified acoustic wave into a radio frequency signal, and a transmission unit for transmitting the radio frequency signal; and at least one interrogator structured and arranged to transmit and receive radio frequency signals such that the at least one interrogator receives the radio frequency signals transmitted by the acceleration sensors and processes the signals to determine whether the vehicle is experiencing a crash requiring deployment of the occupant restraint device. As to the arrangement of sensors, one or more may be arranged in a front or rear crush zone of the vehicle, in a door of the vehicle and/or in a passenger compartment of the vehicle. A sensor may comprise a substrate whereby the means for causing the acoustic wave to be modified based on the measured acceleration comprises bending of the substrate and an acceleration-sensing mass engages the substrate whereby acceleration of the mass changes a property of an acoustic wave on the substrate.

Detailed Description Text (105):
An embodiment of a tire monitoring device in accordance with one embodiment of the invention comprises sensor means for measuring pressure and temperature of the tire, an accelerometer for measuring acceleration of a tread of the tire adjacent the sensor means; and a processor coupled to the sensor means and the accelerometer for receiving the measured pressure, temperature and acceleration and determining

whether the tire is at a non-optimal condition. The processor can also measure a length of time that a tread portion is in contact with the road surface such that a diameter of the tire footprint on the road is obtained. The diameter of the tire footprint is analyzed to determine whether the tire is at a non-optimal condition.

Detailed Description Text (106):
Another embodiment of a tire-monitoring device in accordance with the invention comprises means for monitoring the curvature of the tire as it rotates and means for correlating the curvature of the tire into an indication of an operational state of the tire. The monitoring means may comprise a sensor mounted inside the tire at its largest diameter for measuring, e.g., mechanical strain. The correlation means may comprise a processor for determining a ratio of a time in which the sensor indicates constant strain and a time in which the sensor indicates increased stretch. The sensor can measure acceleration in any one axis, in which case, the correlation means may comprise a processor for analyzing a time of zero acceleration in relation to a time of non-zero acceleration.

CLAIMS:

1. A valve stem assembly for a tire, comprising: an elongate metallic valve stem; a body attached to a lower end of said valve stem; and a sensor unit arranged in said body, said sensor unit comprising a capsule having a chamber, a passageway for providing flow communication between said chamber and an interior of the tire and a plurality of SAW sensors arranged in said chamber.

3. The valve stem assembly of claim 1, wherein said sensor unit further comprises a rigid membrane dividing said chamber into first and second compartments, a first one of said SAW sensors being arranged in said first compartment which is in flow communication with the interior of the tire and a second one of said SAW sensors being arranged in said second compartment whereby said first SAW sensor functions as a pressure sensor and said second SAW sensor function as a temperature sensor.

4. The valve stem assembly of claim 1, wherein said sensor unit further comprises a flexible membrane dividing said chamber into first and second compartments, a first one of said SAW sensors being arranged attached to said flexible membrane, said membrane forming a part of said first compartment which is in flow communication with the interior of the tire and a second one of said SAW sensors being arranged in said second compartment, not responsive to the deflection of said membrane whereby said first SAW sensor functions as a pressure sensor and said second SAW sensor function as a temperature sensor.